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HDTV DISPLAYS:
Subjective effects of scanning standards and domestic picture sizes

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Summary

This Report describes the results of two sets of subjective tests relating to HDTV displays.

The first set investigated the size of display and viewing distances which could or would be accommodated in the home, assuming that flat screen displays will be available in a mature HDTV service. For such a display it was found that a size of between 1 and 1.25 metres diagonal would be practicable and desirable, and that viewing distances of between four and six times picture height would be representative of domestic conditions.

The second set of tests investigated the trade-off on perceived image quality between display field-rate and the number of displayed lines at a constant line frequency. It indicated that there are significant benefits to be had from higher field-rate displays but that perceived resolution is more important than scanning structure/field rate. Thus any increase in the display field rate (e.g. by up-conversion) should not be at the expense of resolution.

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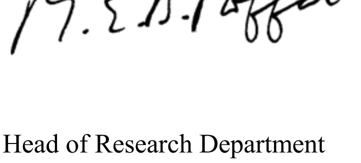

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HDTV DISPLAYS: SUBJECTIVE EFFECTS OF SCANNING STANDARDS AND DOMESTIC PICTURE SIZES

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1. INTRODUCTION

Much of the work of evaluating studio and transmission standards for high definition television (HDTV) has assumed that large screen displays suitable for HDTV will both become available and affordable. As a result, many of the system definitions for HDTV studio and transmission standards have been calculated on the basis that the HDTV image will fill a greater proportion of the human visual field than present-day television and that the viewer will sit at a distance of approximately three times picture height from the display.

Furthermore, display parameters such as picture update rate have hitherto been constrained by economic and other practical reasons unrelated to the human visual system. They have therefore usually corresponded directly with the parameters used in the generation and transmission of television programme material. The need to find efficient and compatible methods of coding HDTV for transmission has enabled source, transmission and display standards to be considered as separable and potentially different (albeit related); this means that techniques devised for transmission bandwidth-reduction, such as digitally-assisted television or DATV[1], also promise new opportunities for successful field-rate up-conversion in the display.

CCIR Recommendation 500-3[2] proposes that subjective assessments of the quality of television pictures be performed at a viewing distance of six times picture height (6H) for pictures displayed at 50 fields per sec. and between 4H and 6H for display at 60 fields per sec. It also notes that, in the USA, the average domestic viewing distance is approximately 10H. The EBU and the OIRT recommend that distances of 4H and 6H be used for subjective assessment. These recommendations have evolved to serve present scanning standards, and there are current moves to modify CCIR Rec. 500-3 to suit the (presumed different) requirements for the subjective assessment of HDTV pictures.

Whilst the relative viewing distances suggested in Rec. 500-3 and Report 405-5 may be appropriate for critical picture quality assessment for present scanning standards, it has not been made clear what HDTV display size is practicable or desirable in the domestic environment nor at what absolute viewing distance a domestic HDTV display would be viewed in practice. At present, the average viewer watches television in a room furnished and arranged for domestic convenience rather than for optimum television viewing. The size and position of the receiver is determined by economic and practical factors such as room size, where the display and seating can conveniently or safely be placed, and the room illumination. If the domestic conditions under which HDTV displays will be used were to be known, it would then be easier to choose some of the HDTV display parameters to match these practical limitations. Some prior work in Japan has been reported[3] in which picture aspect ratio was studied at a fixed viewing distance of 2.5 m for various screen areas. This study was however undertaken in laboratory conditions.

This Report describes the results of subjective tests relating to HDTV displays. The first set of tests investigated the size of display and viewing distances which could, or would, be accommodated in the domestic home in practice. This test assumed that large flat screen displays will be available in the future for a mature HDTV service, and used a series of photographs to simulate such flat displays.

The second set investigated the trade-off between display field rate and number of displayed lines on perceived image quality for an approximately constant bandwidth using a high resolution monitor and an electronic stills store.

2. DISPLAY IMAGE SIZES

In this set of experiments, subjects were asked to take home a set of large high quality photographs and to assess the desirability and practicability of each size both in their present viewing conditions and in conditions rearranged for screen size.

2.1 Description of test images

The test objects comprised a set of five large colour photographic prints of a detailed natural scene (see Fig. 1). The prints had diagonals of 0.5, 0.75, 1.0, 1.25, and 1.5 metres.

Considerable care was taken in the exposure and in the printing to ensure that detail was sharp over the entire picture area, that colour reproduction

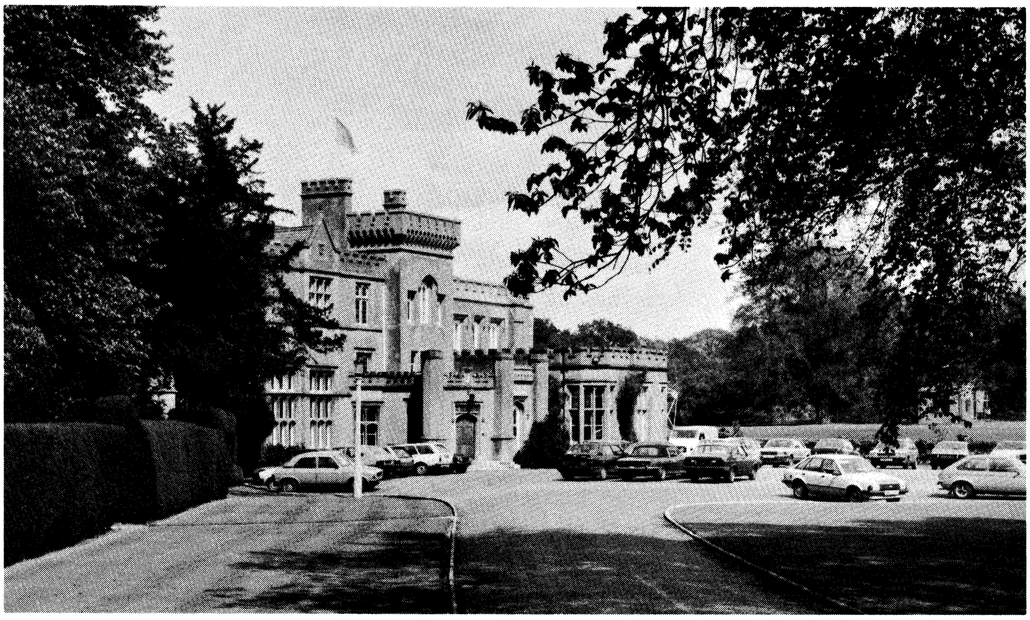

Fig. 1
Test material used for tests of image size.

was consistent and that there was no significant loss of picture detail as the image was progressively enlarged. The negative was exposed using a Sinar P camera with a Symmar 150 mm lens on 102 by 127 mm Kodak Vericolor III professional film 4106, type S. In the enlarging process, the negative image was cropped top and bottom to give a 16:9 print image aspect ratio to represent an HDTV display.

2.2 Description of tests

Participants were first asked to assess which of the image sizes would be practicable, which would be desirable, and which was optimum for their present domestic viewing environment. They were then asked to re-assess these criteria on the assumption that they would be willing and able to rearrange their domestic viewing conditions to accommodate HDTV viewing (including any separate loudspeakers for multi-channel sound). In each case, participants were asked to measure the viewing distance appropriate for the optimum display size and to sketch a plan of their viewing conditions. Fig. 2 shows the 1.0 m diagonal print in a representative domestic viewing arrangement as used in these tests.

2.3 Results

The distribution of the total vote for each image size is shown in Fig. 3 for each criterion. As each participant was explicitly asked to judge if a size was practicable and desirable, every positive vote cast was counted for these two criteria. For the optimum size each participant cast just one vote.

In present viewing conditions there is a good correlation between practicable and desirable sizes and a distinct preference for a size of about 1 metre diagonal on both criteria; the optimum display size was also judged to be 1 metre diagonal. For rearranged viewing conditions there is a slight increase in the mean sizes deemed practicable and desirable. The optimum size (just less than 1.25 metres) was also judged to be slightly larger than for present

Fig. 2
A representative domestic HDTV viewing arrangement.

viewing conditions. The results are summarised in Table 1. The maximum acceptable size of television display is limited by the domestic viewing environment; this is reflected in the results of this simple experiment.

The variation in relative viewing distance for optimum display size is shown in Fig. 4. There is a relatively wide spread of practical viewing distances and a measurable trend towards viewing from closer to the display if viewing conditions were to be rearranged.

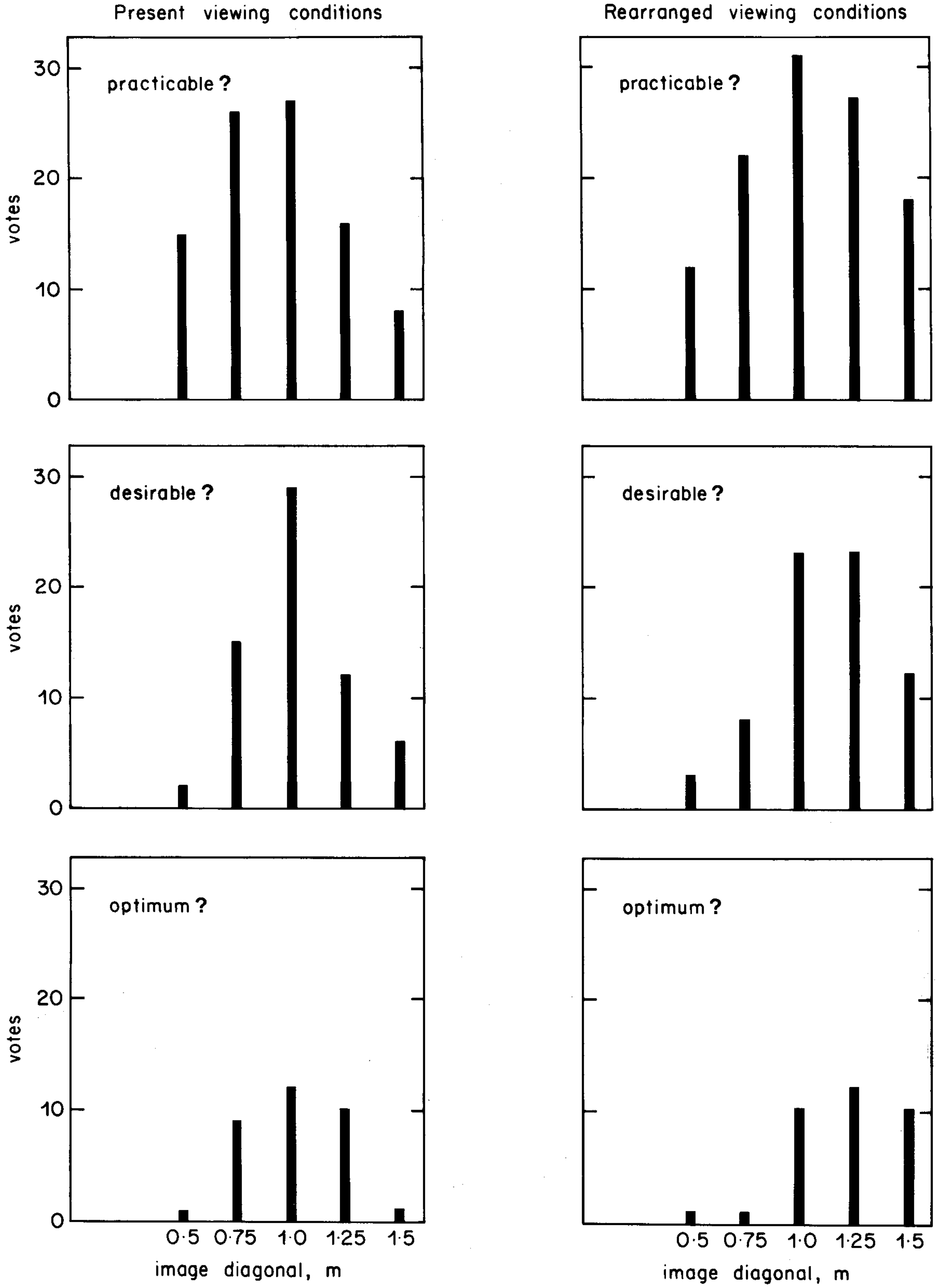

Fig. 3 - Image sizes, votes vs image size.

Table 1: Display size

	Present viewing conditions	Rearranged viewing conditions
Mean practicable	0.93 m	1.04 m
Mean desirable	1.02 m	1.12 m
Mean optimum size	1.00 m	1.21 m
All dimensions across picture diagonal		

The mean relative viewing distance for the optimum image size was 6.1H for present viewing conditions, which distance reduced to 5.6H for rearranged viewing. This indicates that, in general, subjects would be willing to make minor changes to their viewing arrangements so as to sit closer to the display. A small number of subjects did, however, report that they were unable and unwilling to envisage rearranging their viewing conditions for HDTV. Flat-screen displays (perhaps separated from receiving and signal processing circuitry) would facilitate such rearrangements.

In present viewing conditions about 50% of the subjects viewed their optimum image size from distances of between 4H and 6H. When viewing conditions were rearranged, this figure rose to about 60% whilst 20% of the subjects would then have been viewing from less than 4H (Allnatt[4]). From these figures it seems reasonable to infer that, presented with the sort of picture used in the test objects, viewing distances of between 4H and 6H are to be expected in the domestic environment for HDTV.

A note of caution: several subjects remarked that they would not relish watching a 'talking-heads' interview scene on such a large screen from such a close distance. However, as framing and other aesthetic production values are likely to be different for HDTV, this problem may have been overstated. Any problem with 'larger-than-life' images could be alleviated in the receiver by the provision of a switchable 'under-scan' facility.

The variation of viewing distance for other viewers in the room is shown in Fig. 5. The range of viewing distance for a particular household is represented by a vertical bar (or a point) in a

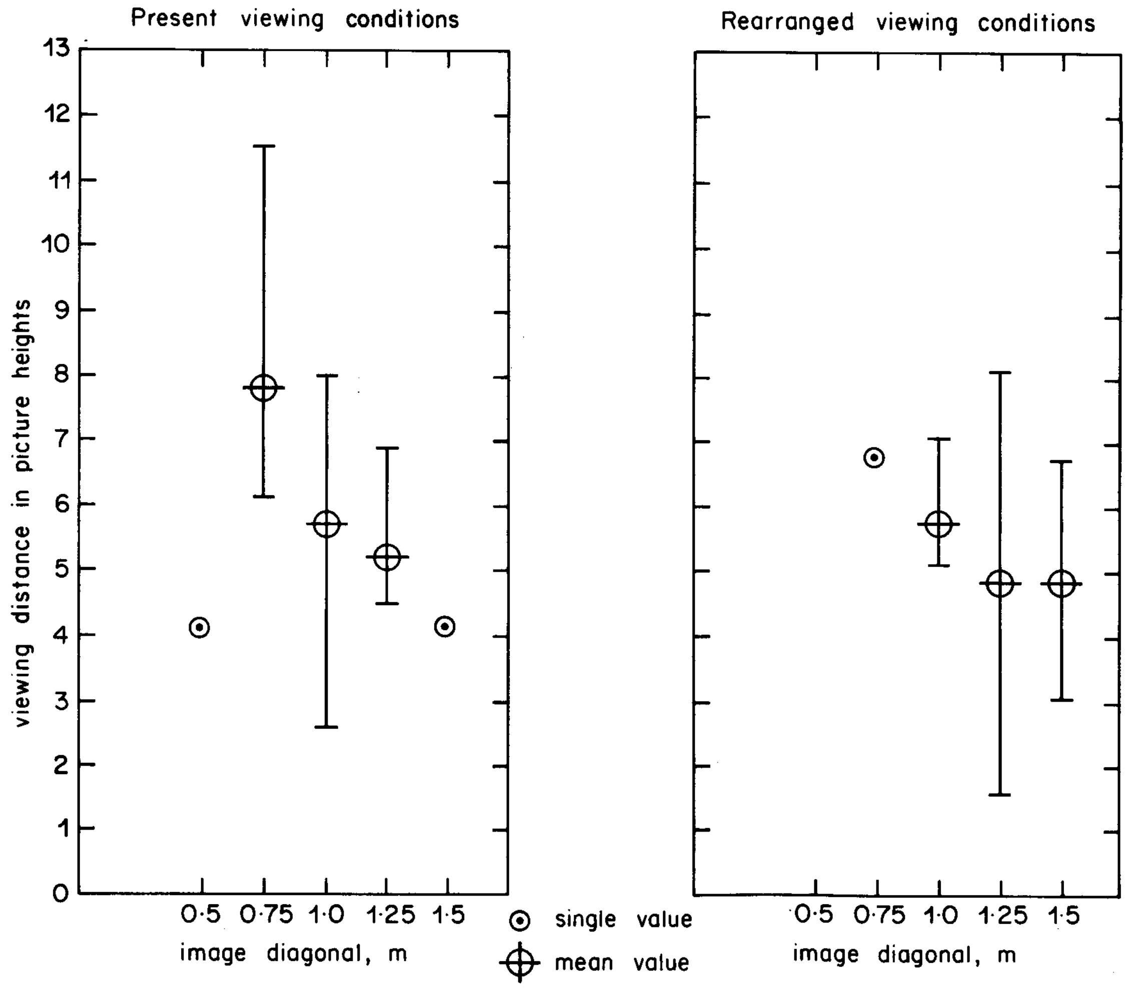

Fig. 4 - Relative viewing distance (picture heights) vs optimum image size for subject as viewer.

corresponding horizontal position in each graph. Again there is a general trend to closer viewing when domestic viewing conditions have been rearranged: the mean viewing distance is 6.0H for present and 5.2H for rearranged viewing. The spread of viewing distance also decreases, the wide spread for present viewing probably reflecting those constraints of domestic convenience on television viewing which were mentioned in the introduction.

2.4 Viewing distances for the subjective assessment of HDTV

As was noted in Section 1, viewing distances of 4H and 6H are proposed for the subjective assessment of present-day scanning standards. On the other hand, US experience shows that the average domestic viewing distance is 10H. Analysis of the data from these tests shows that the average domestic UK distances for viewing 626/50 signals are similar. Thus an approximately two-fold increase in screen size or a halving of the average viewing distance is appropriate for critical assessment.

In the tests on image size, we found that the average preferred distance for HDTV viewing with present domestic arrangements was 6H. By taking the present-day relationship between actual viewing distance and distance for critical viewing as a model, it is worth calculating approximate viewing distances for the critical assessment of HDTV. This yields approximate figures of:

$$6H \times 4H/10H = 2.4H$$

and

$$6H \times 6H/10H = 3.6H$$

Given the overall inexactitude, this could be conveniently simplified to be between 2.5H and 3.5H.

3. DISPLAY SCANNING STANDARDS

The subjective quality of a television picture is influenced by various parameters of the display device. The scanning structure, picture update rate and temporal characteristic of the display affect the visibility of large area flicker, of line structure (both of picture lines and of field lines) and of interline twitter. Furthermore the perceived resolution of the displayed picture is determined both by the horizontal and by the vertical display resolution.

In this set of experiments, subjects were asked to assess the relative differences between a reference HDTV monochrome picture scanned at 60 Hz and the same picture scanned at any of five different display resolutions.

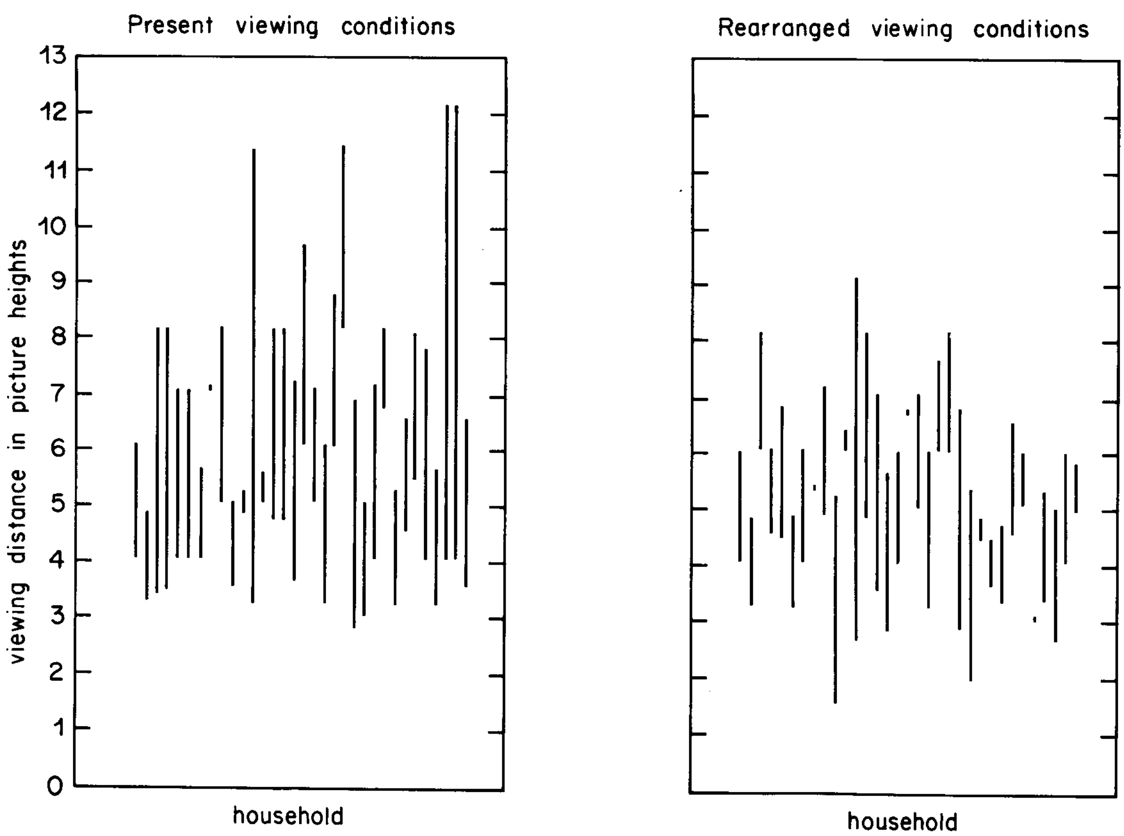

Fig. 5 - Ranges of relative viewing distance (picture heights) vs optimum image size for other viewers per household.

3.1 Equipment used

To generate test pictures, an HDTV stills store was used; it was capable of reconstructing pictures from 54 MHz digital samples with a 22 MHz analogue bandwidth. The storage capacity enabled it to store four different monochrome HDTV pictures and it could be configured dynamically to produce an output picture on any one of the five different display standards.

An HDTV monitor was modified to accommodate the various display standards used. As the field rate was changed, the scan height and the analogue convergence correction were switched synchronously. The convergence correction was only really effective in displayed rasters that were smaller than the full 0.75 m (26") diagonal screen. It was found from experience that satisfactory convergence could be achieved in an active picture area of 50 by 33 cm. This corresponded to an aspect ratio of 4.5:3. The monitor in question required at least 24 blank lines of 32 μs during field flyback and 5 μs in line flyback. The field scan was stable a small fraction of a second after a change in scanning, but with inevitable field roll.

The store scanning algorithm together with synchronisation and control waveform for the monitor were selected by digital control.

3.2 Picture material used

The picture material used was the well-known 'Kiel Harbour' (data provided courtesy of DBP) shown in Fig. 6. This still, derived as it is from a large format photograph, contains a great deal of static detail in the master data. The master data (a 3248 by 2464 file of 8-bit gamma-corrected *RGB* values) was processed using a VAX 11/750 computer. A luminance picture at the master resolution was first calculated. It was then windowed to form a sub-master with a 4.5:3 aspect ratio. This sub-master was then filtered and subsampled to each of the display scanning structures required and 8-bit output data files generated for display. An identical horizontal re-sampling filter was used for all four pictures.

3.3 Scanning structure investigated

Line rate is probably the severest restriction in any domestic CRT display and will, in practice, be set at the highest rate which is economically feasible using contemporary technology. It was not possible to switch the line frequency during the course of this experiment so a constant rate of 31.25 kHz was used.

Of the five display structures chosen, four are of interest to European television systems, being harmonically related to a 50 Hz field rate, whilst the fifth is similar to the Japanese 1125/60 HDTV proposal.

For a constant line frequency, as the field rate is raised or interlace is removed, the number of displayed lines decreases. Hence the chosen structures are as shown in the left hand side of Table 2.

The figures for the active picture area are not the same as the displayed resolution. This is because,

Fig. 6
Kiel Harbour – the picture material used for tests on scanning standards.

at lower field rates, less vertical information can be carried on an interlaced raster than the Nyquist limit would suggest without exciting gross interline twitter in the display. The amount by which usable vertical resolution falls short of the vertical Nyquist limit is a function of field rate and picture material and we have used an 'interlace efficiency factor' to represent this short-fall. In approximate terms it represents the relative bandwidth of a vertical filter which would provide an acceptable twitter performance for that particular scanning structure. It has been determined by experiment and experience and was used to modify the pass and stop band frequencies of the vertical resampling filter. In order to provide realistic pictures with near isotropic pixels, the potential maximum horizontal resolution of 1404 pixels per analogue active line was not used. Instead the resolution was fixed to be isotropic with a factor of unity for the picture displayed at 75 Hz 2:1 interlace. The horizontal resolution corresponds to an analogue Nyquist frequency of 22.5 MHz, which would then be further modified by the 22 MHz reconstruction filter in the DAC. The right hand half of Table 2 gives the interlace efficiency factors and the resultant resolutions used in the picture processing.

Table 2: The five scanning structures used for the tests and the corresponding picture resolutions

Structure		Resolution		
Scanning algorithm	Active area (horiz × vert) (samples)	Interlace efficiency factor	Horizontal pass/stop (cpw)	Vertical pass/stop (cph)
1249/50/2:1	1404 × 1195	0.80	470/645	382/526
625/50/1:1	1404 × 583	(1.00)*	470/645	233/321
1049/60/2:1	1404 × 1001	0.87	470/645	348/479
825/75/2:1	1404 × 781	0.95	470/645	297/408
625/100/2:1	1404 × 583	1.00	470/645	233/321

* = not applicable for a sequential scan
cph = cycles/picture height
cpw = cycles/picture width

NOTE: Whereas the line numbers and line rates in the scanning algorithms are exact, the field rates are nominal, the actual value being the nearest integer to satisfy the requirements for constant 31.25 kHz line rate (e.g. 50 Hz was actually 50.04 Hz).

3.4 Testing method

The EBU relative testing method outlined in EBU Technical Recommendation R-28 1982(E)[5] was chosen. In this method each test comprises a reference picture shown for ten seconds, followed by mid-grey for three seconds, followed by a test picture for ten seconds. The CCIR seven grade comparative testing scale was used. For these tests the methodology had to be altered slightly for practical reasons. Firstly, mid-grey could not be shown in case it flickered or had line structure, which might influence the results. Secondly, the voting period was extended to twenty seconds to allow an observer to register three scores for each test. Thirdly, the observers were sat at 2.5H and 3.8H; this allows for measurements to be taken around the proposed HDTV viewing distance of 3H and is also consistent with the figures derived in Section 2.4. The monitor peak brightness was set at 70 cd/m^2. With the future prospect for brighter displays at HDTV, this figure may be rather conservative and it may be desirable to repeat these tests with the peak brightness set to 100 cd/m^2 or greater when suitable display devices become available.

Thirty-four observers were used, 18 sitting at 2.5H and 16 at 3.8H. Of these 17 were experienced and 17 were non-experienced observers. They were asked to record three scores for each test. For the first score, observers were asked to vote on the quality of the scan structure, dissociating large area flicker, interline twitter, line crawl and line structure from the content of the displayed picture. Secondly, observers were asked to vote on the perceived static resolution of the picture. Finally, they were asked to vote on the overall quality of the display; it was pointed out to them that this vote should not necessarily be an algebraic average of the two previous scores.

3.5 Results

The results for all three voting criteria are shown in Figs. 7, 8 and 9. For each criterion charts are drawn for all 2.5H observers, for all 3.8H observers and all observers at both 2.5 and 3.8H.

As can be seen from the results of the scan structure assessments (Fig. 7) within the limits of the

experiment there are significant benefits to be achieved by using a higher field rate than 60 Hz in the display. In the overall results of Fig. 9, however, subjects weighed resolution considerations as more important than the display structure. For constant display circuit bandwidth the benefit of a higher field rate will therefore be offset by the consequent reduction of resolution.

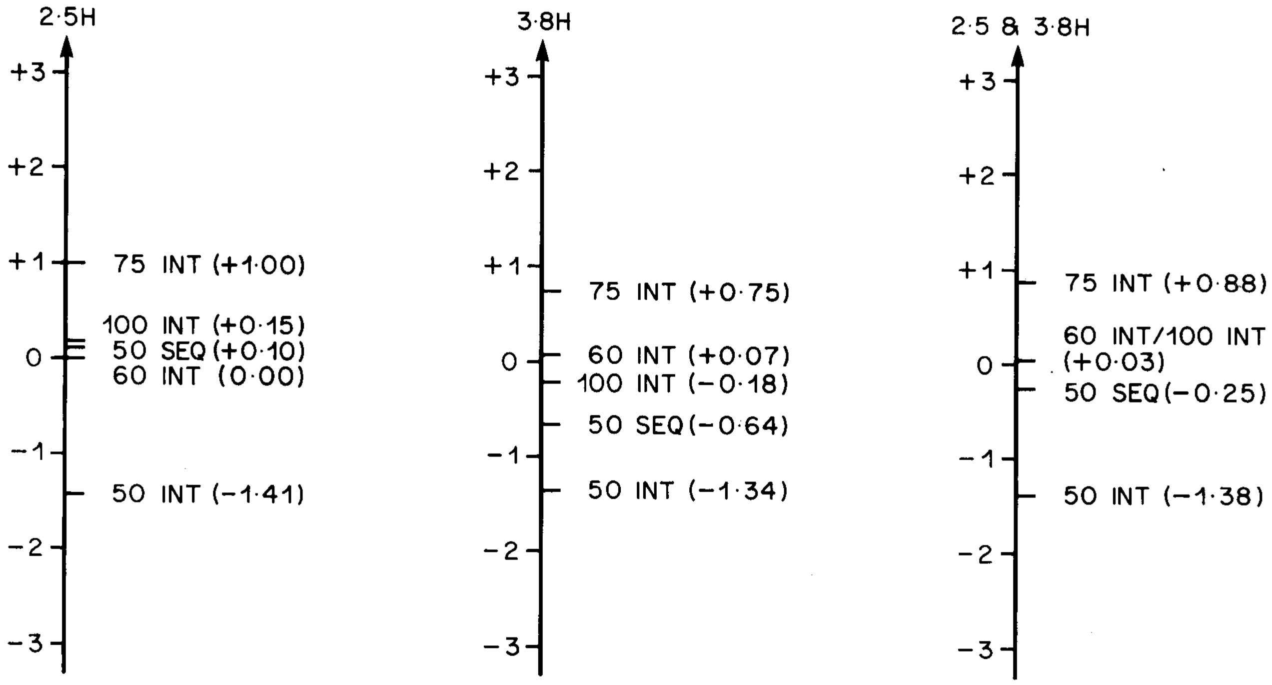

Fig. 7 - The quality of the scan structure.

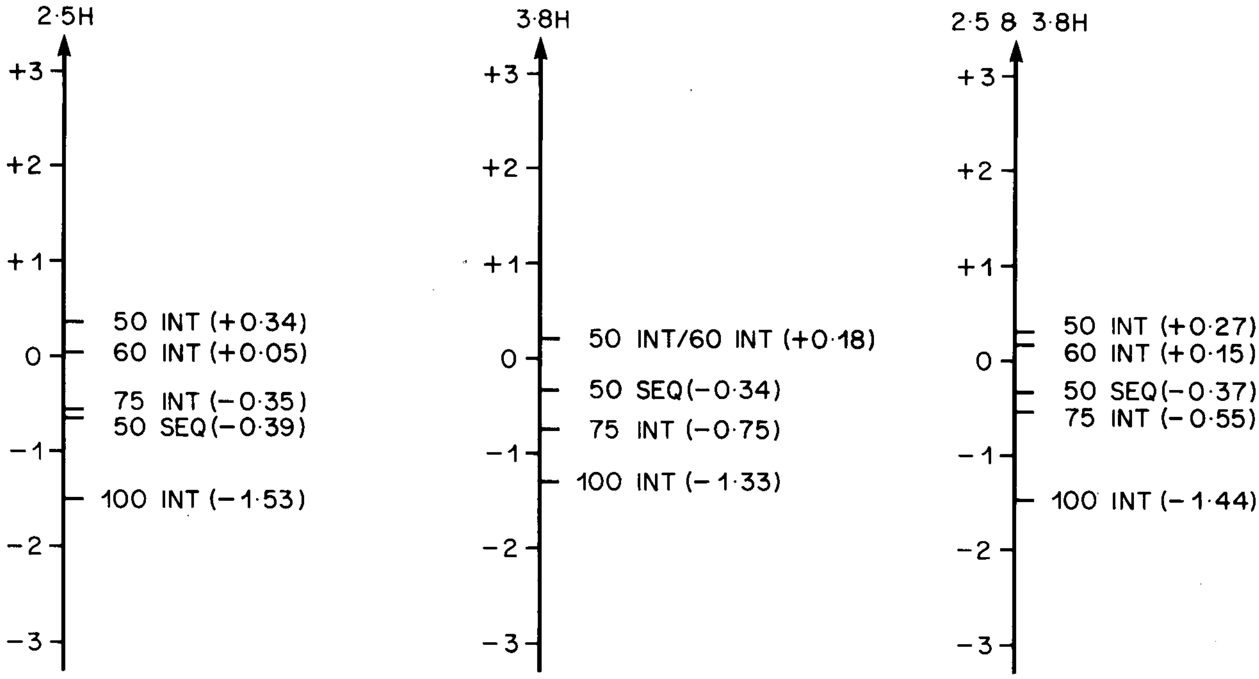

Fig. 8 - Perceived static resolution.

Key: 50 INT : 1249/50/2:1
50 SEQ : 625/50/1:1
60 INT : 1049/60/2:1
75 INT : 825/75/2:1
100 INT : 625/100/2:1

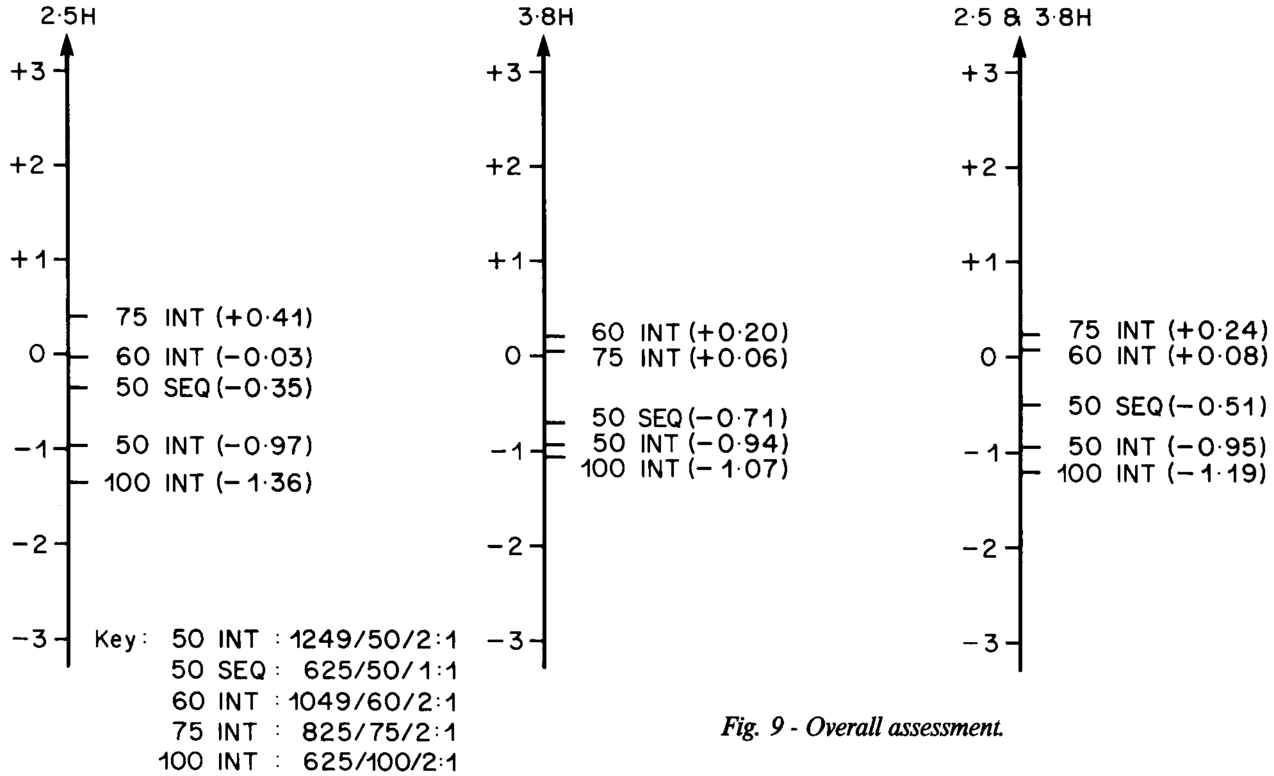

Fig. 9 - Overall assessment.

It should be noted that the apparent poor performance of the 100 Hz interlaced display structure was partly caused by deficiencies in display interlacing. This was manifest as line-pairing with a low temporal component which modulated the line spacing and led to moving coarse horizontal banding; the effect was both very visible and offset the considerable advantages of the flicker-free display. Even with this instrumental problem, however, subjects still preferred the improved flicker performance at close viewing distances.

4. CONCLUSIONS

The results of the tests on display field rate indicated that there are significant benefits to be achieved from using a high field rate in the display. They also showed that perceived resolution was deemed to be more important than the actual structure/field rate used for display. Thus if the display field rate is to be increased it should not be at the expense of resolution.

The results of the survey of image sizes indicated that a flat-screen display of between 1 and 1.25 metres diagonal would be practicable and desirable for HDTV in the home.

With the test image used, 20% of the subjects would have viewed their optimum choice of image size from less than 4H. Viewing distances of four and six times picture height are representative of practical domestic conditions for displays of these sizes. Viewing distances closer than this, possibly between 2.5 and 3.5 times picture height, could be appropriate for critical assessment of picture quality.

The results help to confirm the view that the absolute size of domestic HDTV displays will be determined by practical limits such as room dimensions and the willingness or otherwise of the householder to rearrange family viewing conditions to suit the HDTV display.

5. REFERENCES

1. STOREY, R. 1986. HDTV motion-adaptive bandwidth reduction using DATV. BBC Research Department Report No. BBC RD 1986/5.

2. CCIR, 1986. Recommendations and Reports of the CCIR. 1986. Vol. XI-1. Rec. 500-3 and Rep. 405-5.

3. FUJIO, T. et al. 1982. High definition television. NHK Technical Monograph No. 32, June 1982.

4. ALLNATT, J.W. 1983. Transmitted picture assessment. Wiley.

5. EBU, 1982. Technical Recommendation R-28 1982(E).